X-641-68-151
PREPRINT
NASA TM X- 63182

EXCITATION AND IONIZATION OF He^+ (1s) BY ELECTRON IMPACT

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MAY 1968

GSFC
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Corrected Version

I. C. P. E. A. C., Abstracts of Papers, 1967, pp. 444-445.

Excitation and Ionization of He^+ (1s) by Electron Impact

by

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The binary collision approximation developed by Vainshtein et al[1] has produced satisfactory agreement between theory and experiment for cxcitation and ionization of neutral atoms by electrons, especially for the intermediate and high incident energies. It is of interest to test the validity of the theory for excitation and ionization of ions by electrons. In this paper[2] the theory has been applied to such processes for He^+.

For the electron-Helium ion system let $\vec{r}_1$, $\vec{r}_2$ represent the position vectors of the atomic and incident electrons, and $\vec{k}_1$, $\vec{k}_2$ the momentum vectors of the incident electron before and after the collision. Among the alternate forms for the transition amplitude we choose the one given by

$$T(1, 2) = <\Phi_2 (\vec{r}_1) e^{i\vec{k}_2 \cdot \vec{r}_2} \left| \frac{1}{r_{12}} - \frac{Z}{r_2} \right| \Psi(\vec{r}_1, \vec{r}_2)>, \qquad (1)$$

where $\Phi_2(\vec{r}_1)$ is the wave function of the atomic electron after the collision, $\Psi(\vec{r}_1, \vec{r}_2)$ is the total wave function of the system with a specified asymptotic form, and Z is the nuclear change. Equation (1) is an exact expression for T(1, 2), and the accuracy of T(1, 2) depends on how well $\Psi(\vec{r}_1, \vec{r}_2)$ can be approximated to the exact wave function. We choose $\Psi(\vec{r}_1, \vec{r}_2)$ to be the one given by Vainshtein et al with the appropriate changes for the electron-ion case. The integral (1) is then evaluated similarly to the case of electron-neutral atom collision and with the improvements in the evaluation of the integral introduced by Omidvar[3] and Crothers[4].

The results of the calculation for the transitions 1s→ continuum, 1s→2s, and 1s→2p are shown in Figures 1→3 and compared with experiment and other theories. Few conclusions about the application of the binary collision approximation to collisions between electrons and ions can be drawn until the exchange calculation is completed as some exchange calculations have been know to increase the direct cross section.

A few comments about the figures are in order however. The Coulomb Born and plane Born approximations should agree to within a few percent above 500 eV. The Coulomb Born curve shown in Figure 1 is that of Burgess[5] as shown by Dolder et al[6] who extrapolated Burgess's calculations by use of the plane Born theory. This was an approximate calculation. A later Coulomb Born calculation by Burgess and Rudge[7] showed that the peak should be about 10% higher. The plane Born cross sections, not shown in Figure 1, are about 16% smaller than the correct Coulomb Born cross sections at the peak and are therefore in better agreement with the experimental results. The present theory also converges to the plane Born approximation but at much higher energies. Our curve is still about 10% below the plane Born at impact energies of 100 times the threshold energy. The magnitude of our cross sections near the peak of the curve are quite sensitive to variations of the effective charge. The fact that the experimental results of Dolder et al agree so well with the plane Born approximation at 800 eV is another point against the present theory. The Born exchange calculation of Rudge and Schwartz[8], indicated by the triangles in Figure 1, is in excellent agreement with the experiment, however their theory does contain arbitrarily determined phase shifts.

In the case of excitation the plane Born and the present approximation do not give the correct threshold behavior since in these approximations zero cross sections are predicted at the excitation threshold. For the 1s→2s transition, Figure 2, this defect is for most applications unimportant in the present theory since the cross section increases so rapidly just above threshold. In fact at low energies our curve agrees at least as well with the experimental curve of Dance et al[9] as does the Coulomb Born II calculation of Burgess et al[10]. In this case, the experiment was normalized to the plane Born approximation, between 500 and 750 eV. The validity of the plane Born approximation at these energies has not been definitely established and hence the discrepancy between our theory and the experiment at these energies is not as note worthy as in the case of ionization.

There is no experimental data for the transition $He^+(1s)\rightarrow(2p)$. Therefore in Figure 3 we compare our theory with the close coupling results of Burke et al[11] and with the plane Born curve. Here our cross sections do not increase as rapidly from zero as they did in the 1s→2s case and they will therefore probably be less useful near threshold.

References

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2. This is a corrected version of our paper which was published in the Abstracts of papers, Fifth International Conference on the Physics of Electronic and Atomic Collisions, Leningrad, U.S.S.R., July 1967 (NAUKA, Leningrad 1967), p. 444. Prior to the meeting a mathematical error which substantially changed our results was pointed out by Crothers (Ref. 4). It was then too late to correct the published manuscript but the paper in its present form was presented at the conference.
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Figure Captions

Figure 1. Ionization of He^{+} (1s) by electron impact. The triangles indicate the Coulomb Born exchange calculations of Rudge and Schwartz (Ref. 8), the experiment was by Dolder et al (Ref. 6), and the Coulomb Born calculation by Burgess (Ref. 5). The present theory goes asymptotically to the Coulomb Born approximation at higher energies.

Figure 2. The $1s \rightarrow 2s$ excitation of $He^{+}(1s)$ by electron impact. The sources of the curves are: experiment by Dance et al (Ref. 9); C. B. II - Coulomb Born II by Burgess et al (Ref. 10); C. C. - close coupling by Burke et al (Ref. 11). The first data point given in the C. C. calculation is about 3 eV above threshold. It is not therefore entirely clear how large the peak on this curve is.

Figure 3. The $1s \rightarrow 2p$ excitation of $He^{+}(1s)$ by electron impact. The plane Born and the present theory are compared with the close coupling calculation of Burke et al (Ref. 11).

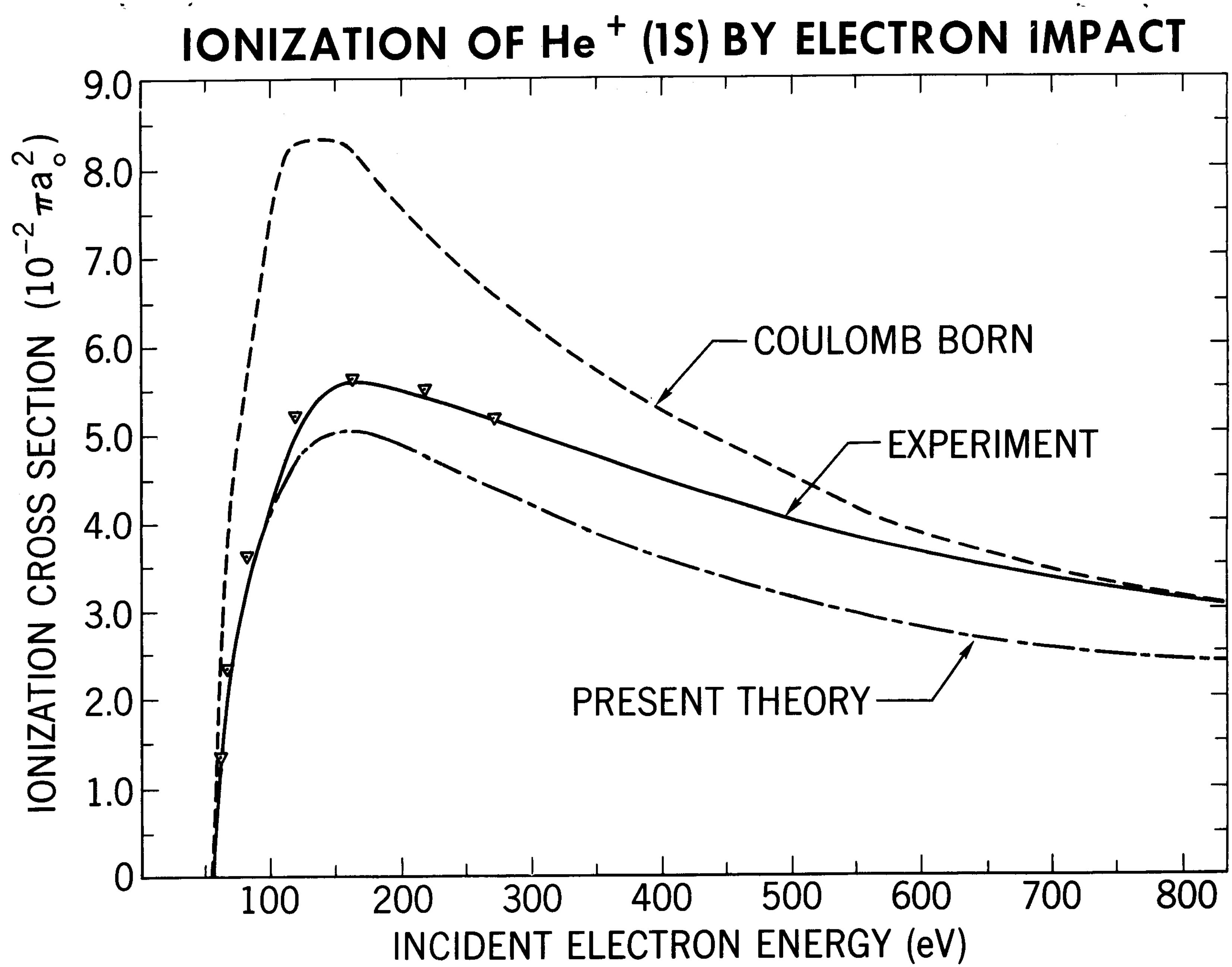
IONIZATION OF He + (1S) BY ELECTRON IMPACT
IONIZATION CROSS SECTION (10^-2 πa_o^2)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
100
200
300
400
500
600
700
800
INCIDENT ELECTRON ENERGY (eV)
COULOMB BORN
EXPERIMENT
PRESENT THEORY

Fig. 1

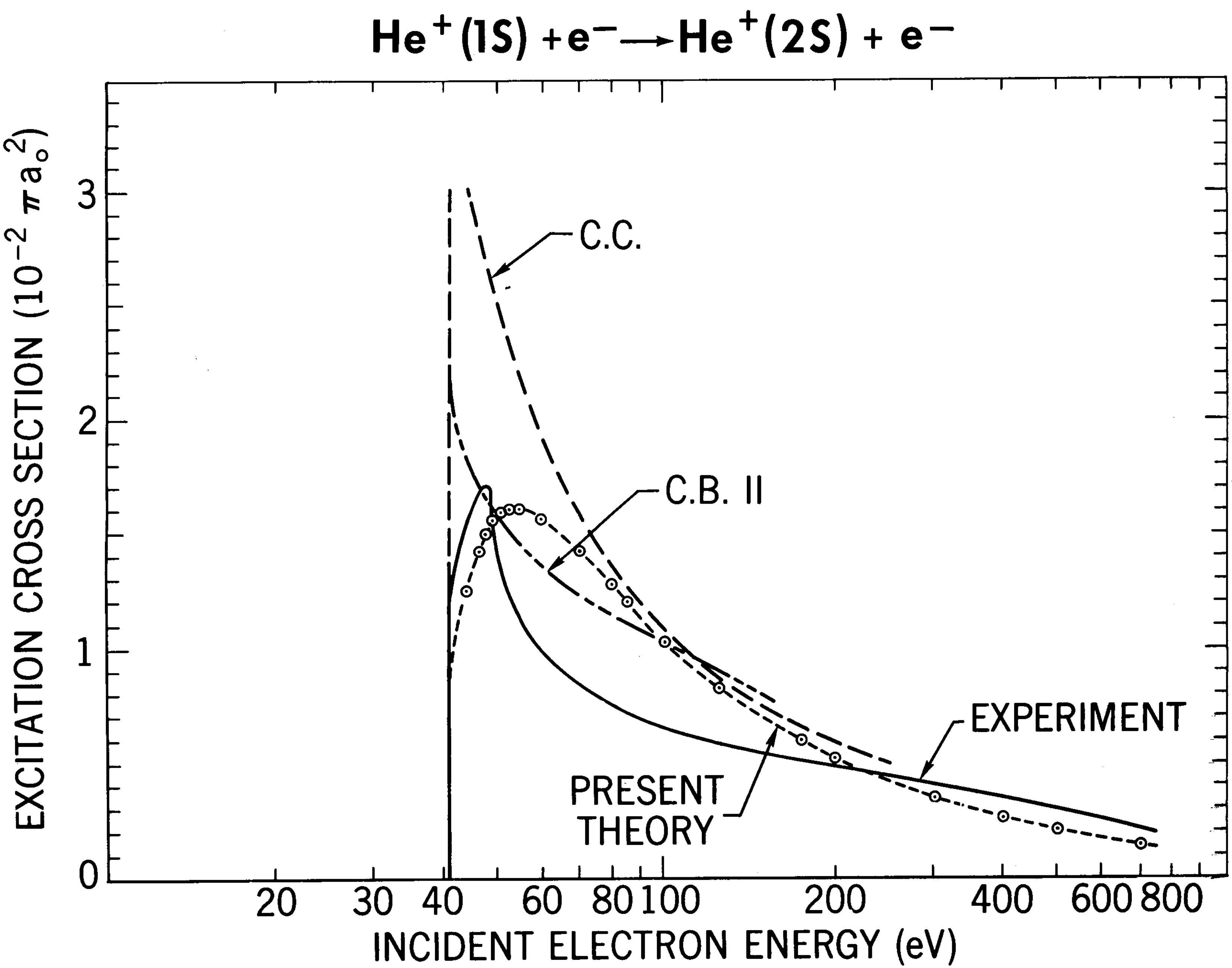
$He^+(1S) + e^- \longrightarrow He^+(2S) + e^-$
EXCITATION CROSS SECTION ($10^{-2}\ \pi a_o^2$)
3
2
1
0
C.C.
C.B. II
EXPERIMENT
PRESENT THEORY
20
30
40
60
80
100
200
400
600
800
INCIDENT ELECTRON ENERGY (eV)

Fig. 2

$e^- + He^+(1S) \rightarrow e^- + He^+(2P)$

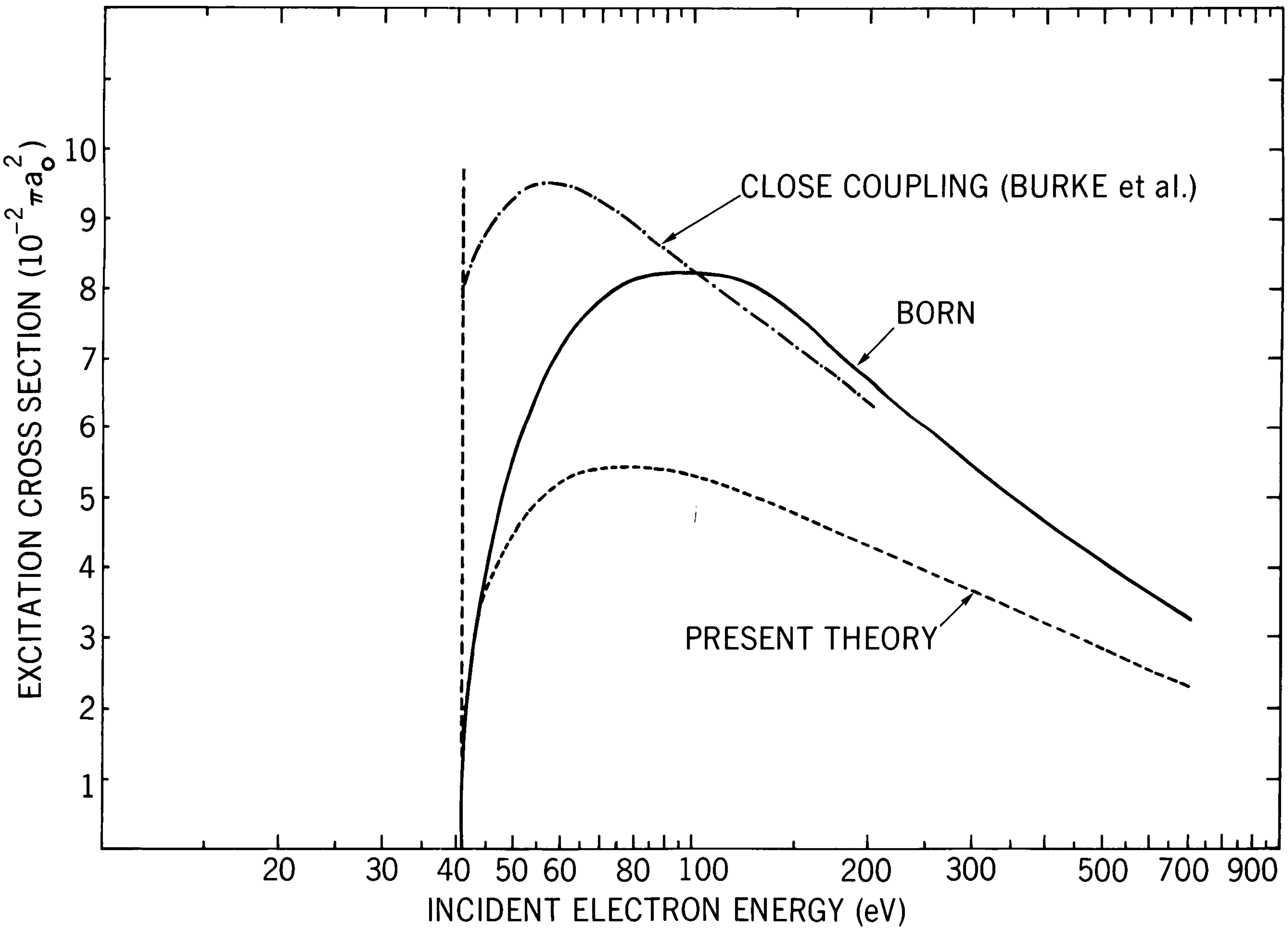

Fig. 3